Soil Moisture Experiments 2004 (SMEX04) Polarimetric Scanning Radiometer, AMSR-E and Heterogeneous Landscapes

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Abstract-An unresolved issue in global soil moisture retrieval using passive microwave sensors is the spatial integration of heterogeneous landscape features to the nominal 50 km footprint observed by most satellite systems. One of the objectives of the Soil Moisture Experiments 2004 (SMEX04) was to address some aspects of this problem, specifically variability introduced by topography and convective precipitation. Other goals included understanding the role of the land surface in the North American Monsoon System. Data were collected during the month of August 2004 at three scales; ground based point measurements, aircraft passive microwave mapping, and satellite observations using AMSR-E and other sensors. SMEX04 was conducted over two regions: Arizona - semi-arid climate with sparse vegetation and moderate topography, and Sonora (Mexico) - moderate vegetation with strong topographic gradients. The Polarimetric Scanning Radiometer (PSR/CX) was flown on a Naval Research Lab P-3B aircraft as part of SMEX04 (11 dates of coverage over Arizona and 10 over Sonora). General meteorological conditions, the PSR/CX data sets and selected comparisons of this data to AMSR-E are presented.

I. Introduction

Field experiments in support of remote sensing, hydrology and climate have included catchments throughout North America. These experiments have been intensive efforts ranging from one to six weeks in duration. The basic approach used in these experiments has been to collect ground-based samples of soil moisture in conjunction with aircraft flights at the same time as satellite overpasses. The aircraft instruments operate in low frequency microwave wavebands that are well suited for the measurement of soil moisture. The aims of these experiments have been: validation of remotely sensed data from aircraft and/or space-borne microwave sensors, the mapping of spatial and temporal variability of soil moisture, the relationship of soil moisture to vegetation and the near-surface atmospheric characteristics, and the collection of in-situ gravimetric data for soil moisture for validation of the land surface hydrological models used to simulate the watershed at pre-specified spatial and temporal resolutions.

SMEX04 builds on preceding experiments by focusing specifically on topography, vegetation and strengthening the soil moisture components of the North American Monsoon Experiment (NAME) (http://www.joss.ucar.edu/name). One of the main objectives of NAME is to improve prediction of warm season precipitation. Warm season precipitation is highly dependent on convection, which, in turn, is controlled, at least in part, by soil moisture and surface temperature. Therefore, an accurate characterization of spatial and temporal variability of soil moisture is critical to NAME.

This paper focuses on preliminary results from the SMEX04 aircraft campaign involving the PSR/CX and relationships between the aircraft and satellite observations. Additional details on SMEX04 can be found at http://hydrolab.arsusda.gov/smex04.

II. SMEX04 Description

SMEX04 involved four complementary elements; in-situ soil moisture networks, aircraft mapping of soil moisture, intensive sampling concurrent with aircraft missions, and satellite products. The timing of SMEX04 and the NAME Enhance Observing Period were driven by the North American Monsoon system. Rainfall statistics clearly indicated that the field experiment should be centered around the period roughly mid-July to mid-August, when the number of rainy days is large and the possibility of having a having flights prior-to and subsequent to heavy rainfall is high. Due to problems involving flight readiness of the aircraft, the start of SMEX04 was delayed until the beginning of August and was interrupted by a second aircraft failure. The flight dates and coverage are summarized in Table I.

Within the NAME area of interest, two regional study sites (~50 km by 75 km) were established; Walnut Gulch Arizona (AZ) and Sonora Mexico (SO). The general vegetation conditions for the two sites are clearly illustrated in the Landsat image shown in Figure 1. Vegetation biomass

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and topographic variability in AZ were both less than those observed in SO.

TABLE I.
SMEX04 PSR/CX and AMSR-E Coverage

	Aircraft Mission		Satellites		Antecedent Precipitation	
August	AZ	SO	AMSR-E	WindSat	AZ	SO
5	X	X	X	X	X	T
6					T	X
7		X	X			
8	X	X			X	X
9	X	X	X	X		X
10	X	X	X	X	X	T
11				X		
12	X	X	X		T	X
13	X	X				T
14		X	X	X	X	X
15				X	X	X
16			X	X	X	X
17						X
18			X			X
19			X		T	T
20				X		
21			X	X		
22				X		
23			X			
24	X	X				
25	X	X	X		X	X
26	X	X	X	X		

Arizona Study Region

The core of the Arizona region (AZ) is the USDA-ARS Walnut Gulch Experimental Watershed (http://tucson.ars.ag.gov/unit/Watersheds/WGEW.htm). The Walnut Gulch Experimental Watershed encompasses 150 square kilometers and is representative of brush and grass covered rangeland found throughout the semi-arid southwest. Elevation of the watershed ranges from 1250 m to 1585 m MSL. Cattle grazing is the primary land use.

Soils on the Walnut Gulch Experimental Watershed are generally well-drained, calcareous, gravelly loams with large percentages of rock and gravel at the soil surface. Soil surface rock fragment cover (erosion pavement) can range from nearly 0% on shallow slopes to over 70% on the very steep slopes.

The Walnut Gulch Experimental Watershed is densely instrumented with rainfall recorded on a continuous basis at 88 locations. Recently, as part of a project sponsored by the NASA Aqua Calibration/Validation Program twenty-seven soil moisture probes have been installed at twenty-one locations inside or near the 150-km2 watershed, all of which include a 5 cm depth observation. All data are recorded at 30-minute intervals and are automatically reported to a data archiving location.

Sonora Study Region

Some of the regional characteristics presented for the AZ region apply to the Sonora (SO). There is more significant topographic variation and a greater amount and mixture of vegetation within the area of Sonora that was selected. The subtropical vegetation in the region showed significant increases in biomass and vegetation water content in response to the rainfall that occurred prior to SMEX04.

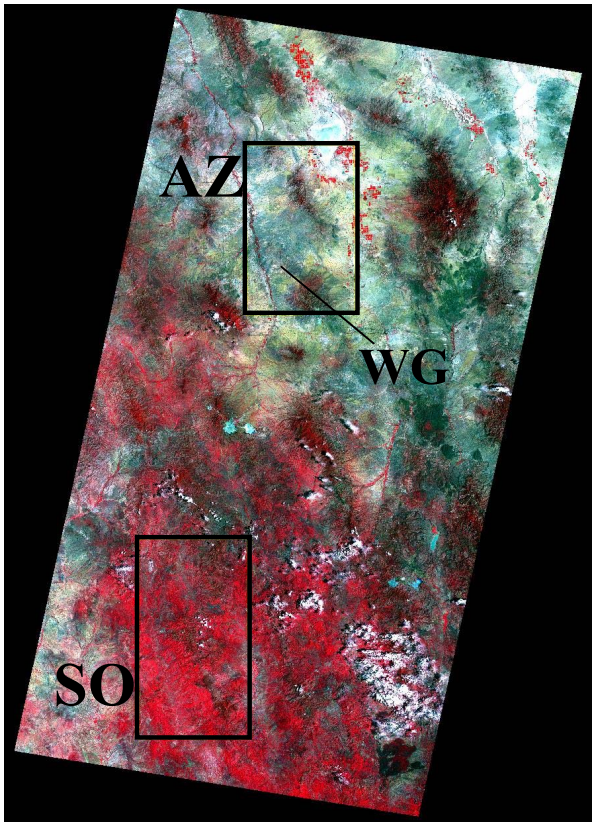

Figure 1. Landsat image of the SMEX04 region and study areas obtained on July 29, 2004.

Soil moisture instruments (Vitel Hydraprobes) were installed at 14 locations distributed over a 50 by 90 km domain in the SO region. Each site also includes a raingage. All sites include a 2.5 cm depth sensor providing both soil moisture and temperature. Data are recorded at 20-minute intervals.

SMEX04 Field Campaign Soil Moisture Sampling

Ground based observations during SMEX04 included a combination of *insitu* and mobile soil moisture data collection. The *insitu* portion was described in the previous sections. This was supplemented with more intensive ground based sampling using traditional methods on aircraft/satellite coverage dates.

Three different sampling schemes were employed; regional, watershed, and topographic gradient. The goal of regional soil moisture sampling was to provide a reliable estimate of the volumetric soil moisture (VSM) mean and variance within a single satellite passive microwave footprint (~50 km) and multiple EASE-grid 25 km cells at the nominal time of the Aqua AMSR-E overpass (1330 local standard time). For AZ, a grid of 40 sites was sampled each date over a 50 km by 75 km domain. In SO, up to 50 sites were sampled in the 50 km by 90 km domain. These measurements are to be used primarily to support the AMSR –E based microwave investigations; therefore, the regional

sampling was conducted within a +/- two-hour time window of the satellite overpass.

Regional sampling in the AZ region was complemented with more intensive watershed sampling at 64 raingage locations within the WG watershed. Topographic gradient, sampling was conducted only in SO and consisted of a single transect of 30 points

PSR/CX and Aircraft Mission Description

Aircraft observations provide the critical bridge for scaling and integrating the point observations to the coarse satellite footprints. In addition, the higher resolution aircraft soil moisture products are of value in more intensive hydrologic investigations. An NRL aircraft (P-3B) was used in SMEX04 as host to the PSR/CX instrument, which simulates the low frequency channels of AMSR-E.

The PSR is an airborne microwave imaging radiometer operated by the NOAA Environmental Technology Laboratory for the purpose of obtaining polarimetric microwave emission. It has been successfully used in several soil moisture experiments (Jackson et al. 2002, Bindlish et al. 2005, Jackson et al. 2005).

A typical PSR aircraft installation is comprised of four primary components: scanhead, positioner, data acquisition system, and software for instrument control and operation. The scanhead houses the PSR radiometers and antennas. The PSR/CX scanhead channels are (C-band) 6.00, 6.50, 6.92, 7.32, (X-band) 10.64, 10.69, 10.70, 10.75. All channels have at least dual polarization. Beamwidths are 10^o for C-band and 7^o for X-band.

For SMEX04, the system operated in an imaging mode using conical scanning at 55^o incidence. System parameters that are significant for mission design are listed in Table II.

TABLE III.
PSR/CX Flightline and Mapping Features for SMEX04Channels

Location	Regional
Altitude (AGL) in m	7300
Number of f flight lines	8
Flight line length (km)	90
Flight line spacing (km)	19
Scan period (seconds)	3
Incidence angle (deg)	55
3-dB footprint resolution	3.0 km at 6 GHz 2.0 km at 10 GHz

Considerations and constraints on mission design (based on SMEX04 specific objectives, and past experience with similar campaigns) included: the intensive observing period was August 3 – August 26, 2004, a daily mission duration of no more than five hours, the coverage was timed to bracket the afternoon AMSR-E overpass time of 1:30 pm, coverage of as large as possible spatial domain (subject to other constraints) in order to increase the probability of observing a wide range of conditions (this recognized the spatial variability of rainfall in the region), and an altitude of approximately 7300 m above sea level for the mapping flightlines.

III. PRELIMINARY RESULTS

The overall quality and value of the SMEX04 data set was impacted by the rainfall during the campaign and the performance of the aircraft platform. In terms of rainfall, it was more widespread and larger amounts in SO than AZ. The SO region is more challenging to interpret because of the higher levels of vegetation and topography.

An engine failure on the P-3 resulted in the lose of ten days of coverage in the middle of the campaign. Unfortunately this was also a period of significant rainfall, resulting in the loss of potentially valuable information.

The PSR/CX data sets have been reprocessed following procedures described in Jackson et al. (2005). The effect of local topography on beam positioning was corrected using DEM databases for the two domains.

PSR/CX C-band images for each day are presented in Figures 2 (AZ) and 3 (SO). These should be interpreted with reference to Figure 1. Not all of the daily coverage images are complete due to some data loses resulting from aircraft operations or instrument problems. Consistent spatial structure and temporal patterns are apparent in both regions. The range of brightness temperature is very different.

Figure 4 is a comparison of the average PSR/CX TB versus the average PSR/CX TB for the same channel on each day in each region. Based on comparisons of C and X band channels, there is evidence of RFI in the AMSR-E C band data over AZ. The observed range of TB for AMSR-E is less than that of the PSR/CX, which may be associated with scaling. Further analyses are ongoing.

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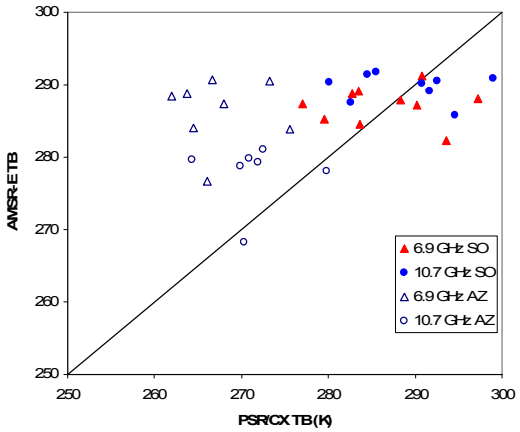

Figure 4. Comparison of H polarization AMSR-E and PSR/CX data over the SO and AZ regions during SMEX04.

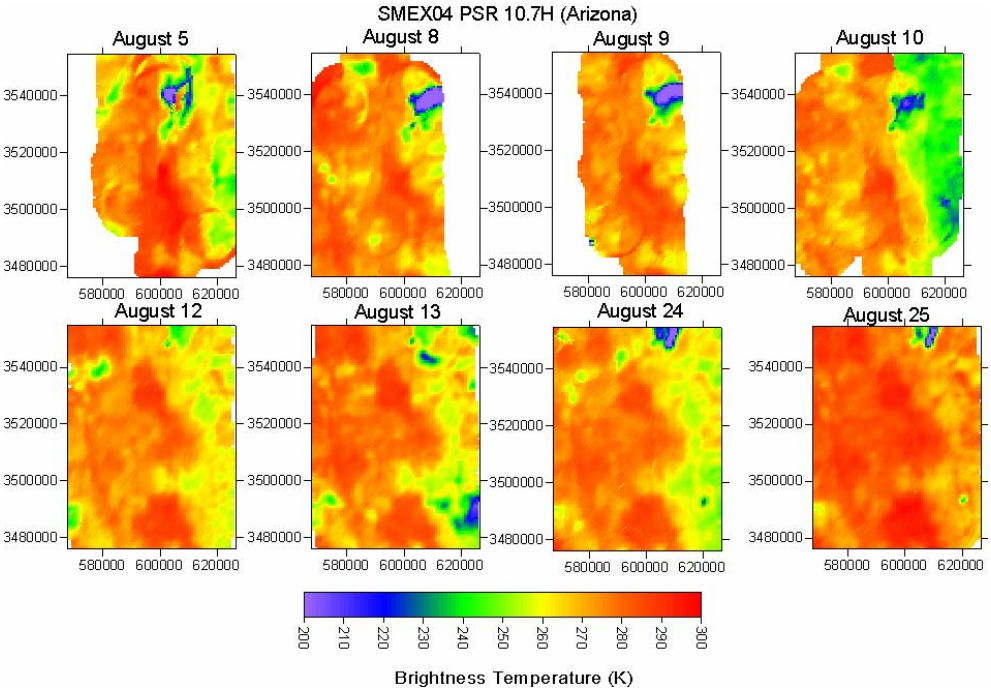

Figure 2. SMEX04 AZ region brightness temperature images for X-band (10.7 GHz) H polarization. (Vertical axis is Northing in m and Horizontal is Easting in m)

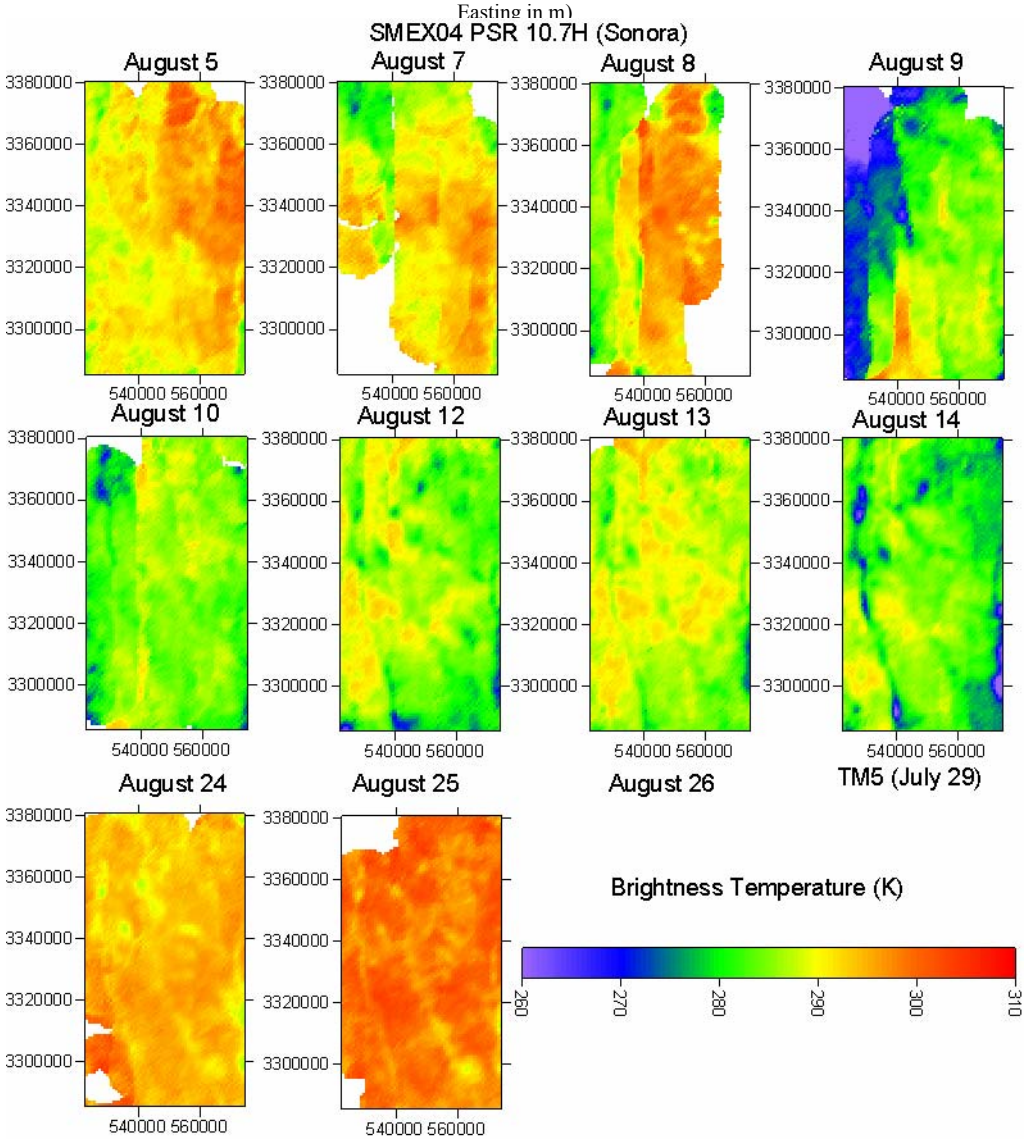

Figure 3. SMEX04 SO region brightness temperature images for X-band (10.7 GHz) H polarization. (Vertical axis is Northing in m and Horizontal is Easting in m)